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16. Abstract Sensitivity to brightness is greater in the peripheral regions of the retina than in the center. This sensitivity is a maximum at a certain distance from the center, which depends on the direction, and then slowly declines further out. The peripheral retina is more sensitive than the center to rapid motion. In order to make the alternating sectors of a rotating disc blend into one another, a higher rate of rotation is required in indirect vision than in direct vision. These properties of the eye seem useful for vision, and offer substantial advantages with respect to perception of objects upon which the eye is not fixed and of motions occurring at the boundaries of the field of vision. It is very likely that the outer segments of the rods, acting as catoptric instruments, bring about this increased sensitivity of the retinal periphery, which would also explain the different distribution of rods and cones in the human retina.

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BRIGHTNESS SENSATION IN INDIRECT VISION

A. Kirschmann

When a sensation stimulates the sight of the retina and is *447
perceived, so that we lift it to the center of our attention, we usually move the image of this object by appropriate motions of the eye toward the Fovea centralis, the point of clearest vision. However, it is not absolutely necessary that the external and internal "foci" always coincide. With a little practice, it is easy to direct one's attention at indirectly seen objects while keeping the eye fixed on a previously chosen point.

The almost unconscious use of indirect vision is much more frequent. It is invaluable in achieving orientation in space, in walking and running, and in other bodily motions, but precisely because the sensations involved are just perceived and not "apperceived", indirect vision is usually underrated. In many activities, indirect vision is almost as important as direct vision, e.g. in painting and drawing. If the eye is covered by a tube painted black on the inside, with a small opening at the front, only the point of clearest vision receives light, and it is interesting to observe that one can hardly orient oneself any longer after glancing around for a bit.
If the eye is covered in this fashion and an attempt is made to draw /448
figures on a blackboard, the shapes produced are very distorted, although the tip of the chalk can be seen very clearly and the observed point can move along the lines being drawn. However, if a device is placed before the eye which prevents access of light to the central fovea, but does not obstruct the rest of the retina, and even though no object can be seen distinctly, it is still possible to orient oneself in space. Also, when attempts are made to draw simple geometrical figures, the lines don't look very good and are often broken, since the tip of the chalk and its immediate vicinity are invisible, but the shapes as a whole are relatively correct.

* Numbers in the margin indicate pagination in the foreign text.

Neither in reading do we operate exclusively with direct vision. We do not focus on each individual letter, as the correcter ought to do. Instead the fixation point jumps from one word to next, and the number of letters seen distinctly is just one, or in longer words, at most two. The others are seen indirectly, but still recognized. When children learn to read, training the indirect vision plays an essential role. This may explain why very myopic, but otherwise quite intelligent children usually take much longer than children with normal vision to learn to read smoothly. Since they must bring the writing very close to the eyes, the image of the words occupy a much greater area on the retina, and only very small groups of symbols can be seen at a single time.

The fact that direct vision is not absolutely necessary for reading can be deduced from the possibility of reading a line of a book without fixing on it. With a little practice, it is possible to read the second or even the third above or below that upon which the eye is focused. It should be mentioned that the small German characters can be recognized better than the Latin letters in indirect vision, while the Latin capitals cause less difficulty than German capitals.

The importance of indirect vision must therefore not be underestimated. However, while we can take precise account of perceptions /449
triggered by stimulation of the center of the retina, we are usually not very aware of perceptions received by the side of the retina, although the sides contribute greatly in virtually all visual activity. Therefore, we do not quite realize the differences between direct and indirect vision, and it requires special effort to isolate the sensations produced by stimulation of the side of the retina and to focus the conscious attention upon them. Consequently, it is very difficult to study indirect vision, and this results in a great temptation to subscribe to the conventional viewpoint that sensitivity of the retina generally decreases toward the periphery. Nevertheless, we will eventually show that this view is unjustified in a certain sense.

Two light sensations from identical physical sources but received on different sections of the retina can differ in three ways:

1) in clarity,
2))in quality of perception,
3) in intensity.

As for clarity, it certainly decreases toward the periphery because of the unfavorable refraction and accommodation conditions. These do not seem to be the only causes, since observations on rabbit eyes have shown that the retinal images have sharp contours in the peripheral sections. Therefore, the lack of clarity of perceptions is best ascribed to the unequal distribution of perceiving terminal organs, which are densest in the fovea centralis, but are spaced farther apart toward the periphery.

Regarding the quality of perception, visual images on the side of the retina experienced quite substantial modifications. It is well known that only the colors yellow and blue are perceived at some distance from the center of the retina, while no colors at all are recognized at greater distances. Only differences in brightness can /450 be perceived. Hence, the perceptions supplied by the perpheral retina are dnot as good as those of direct vision. However, here we ine counter a peculiarity which is in complete conflict the simple assumption that sensitivity to light decreases toward the periphery. The changes undergone by colors in indirect vision are quite different from those caused by a reduction in objective brightness. The third of the possible differences, namely intensity, is the one which we will deal with in some detail below.

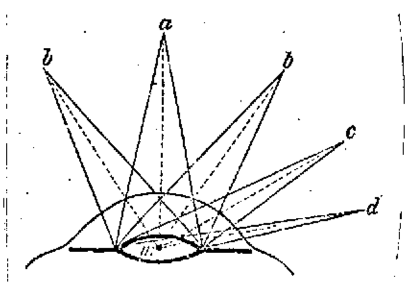

Fig. 1

Now with regard to the objective brightness of the retinal image, it is easy to see that it must gradually decrease from the center toward the periphery. If a, b, c, and d in Fig. 1 are luminous points of equal brightness and all equally distant from the center m of the pupil, the amount of light reaching the interior of the eye from each of the points is obviously measured by the vertex angle of the cone with the pupil as the base and the luminous point as the vertex. Even when the light source is only a moderate distance away, the diameter of the pupil is much smaller than the side of the cone, so that the base of the cone can be replaced by a planar cross section at right angles to the central line of the cone. As a simple calculation shows, however, these elliptical cross sections are roughly proportional to the cosine of the angle of incidence of the light. Therefore, the decrease in objective brightness of the retinal images can be represented by a line very close to a section of the cosine curve. (Strictly speaking, the line coincides with the cosine curve only when the luninous points are infinitely remote; in every other case, the line depicting the bright- /451 ness decrease has a somewhat greater curvature than the cosine curve.)

The fact that the retinal images on the periphery are actually dimmer is confirmed by the following simple experiment. If a very bright light source is placed in front of the eye, the pupil contracts. If the angle of incidence on the eye produced by the light source is increased, while the distance of the light source from the eye remains constant, the pupil again expands, and the greater the angle of incidence, the greater the increase. The reflection-induced innervation of the sphincter pupillae is less in the second case, and since the intensity of innervation depends on the magnitude of the stimulus, we may conclude that the stimulus as well was less, in other words, the retinal image was dimmer.

At this point, we should draw the reader's attention to the fact that it is highly unlikely that the unequal distribution of the cones and rods constituting the receiving terminal organs, which certainly must affect the clarity of perceptions, would also influence the intensity of sensation. We fill out the space between the individual nerve elements with the sensation transmitted by the latter, regardless of whether the intervening space is large or small, as is adequately demonstrated by the well-known filling out of the blind spot. If we generate a printed figure at the edge of the retina, it has the form depicted in Fig. 2. It appears bright against a dark background, and dark against a bright background. If the printed figure is of considerable size, the space around a appears dark in an illuminated field of vision; if the figure is smaller, the area around a is seen as bright, and the line xy corresponding to the periphery of the retina is perceived. Hence, in this case, we even fill out the space beyond the boundary of the receiving organ with the sensation prevailing in the surroundings. The difference in number and arrange- /452 ment of rods and cones in the peripheral regions can therefore influence the sharpness of the (subjective) image, but cannot change the sensation of brightness.

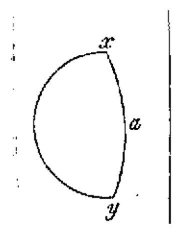

Fig. 2

Having established that the objective brightness of the retinal image decreases toward the periphery, we must now ask whether this objective decrease in intensity corresponds to a parallel change in perception.

If the retina were equally sensitive at all points, the light sensation produced by an object would have to decrease in intensity when the object was moved away from the center of the field of vision, while remaining equally distant from the eye. An evenly illuminated surface would therefore have to appear brightest at the point upon which the eye was fixed; toward the sides, its brightness would have to apparently decrease. However, this is not at all the case. Instead, a uniformly illuminated surface actually looks like one to us, and we do not have the impression that the field of vision was darkening toward the periphery. Shifting an object out of the center of the field of vision always changes the clarity of the image, and can sometimes change the quality of the sensation, but never gives rise to a marked change in subjective brightness. While the color of indirectly viewed objects seems different, and the objects are less clear in outline and depth perception, they still seem to have the same brightness as when they were viewed directly.

This cannot be attributed to fatigue phenomena, as was done by Charpentier [2] and others, supposing that the central part of the retina arrives at a state of fatigue because of its continuous exposure, unlike the less exhausted regions, so that this phenomenon would compensate to a certain extent for the decrease in brightness toward the periphery. As explained above, we do employ the side of the retina just as continuously as we do the central part; we /453
are just not as conscious of this utilization. The images provided by the fovea centralis are consciously registered, while the sensations triggered by the activity of the peripheral retina are generally registered unconsciously. However, the retina is not responsible for this difference; if the restriction of conscious perception to the center of the retina really caused fatigue at the point of most acute vision, the fatigue would have to stop and the opposite state commence during experiments in which the attention is directed at indirectly viewed objects for some time. However, not the slightest indication of such a change has been observed.

It might also be objected that a type of illusion occurs, so that images on the periphery of the retina have lower objective and subjective brightness, but that we are accustomed to seeing things as we know them to be, and thus have the tendency to smooth out brightness differences between direct and indirect vision due to the nature of our eye. In my opinion, this objection is clearly refuted by Aubert's experiments [3] to determine the stimulus threshold. In a completely dark room and with a sufficiently adapted eye, Aubert observed a thin platinum wire, which could be made incandescent by electrical current. The lowest perceptible brightness of the wire he estimated to be 1/300 of the brightness of the full moon. When Aubert did not look directly at the wire, it remained visible due to indirect vision on the entire retina, even though it was just preceptible in central fixation. There is only one possible explanation: for the periphery, where the retinal image is actually much dimmer, as was explained, the stimulus does not have to be as strong in order to produce the same intensity of perception. In other

words, the periphery of the retina is more sensitive to the light than the center. Aubert did not draw these conclusions from his /454
observations, but attempted to explain it by "differing adaptation states in the central and peripheral regions of the retina."

Having discovered that the decrease in objective brightness of the retinal image on the periphery due to the optical equipment of the eye is more or less compensated for by an increased sensitivity of the organs of indirect vision, we now encounter the question of the degree of this compensation.

We saw earlier that the objective intensity decrease of the retinal image can be illustrated by a curve similar to the cosine. In Fig. 3, the angle of incidence is the abscissa in an orthogonal coordinate system, and the associated intensity of the retinal image is the ordinate. The curves PQ thus represents the decrease in brightness. If we also had the curve of increasing sensitivity, a suitable combination of the two curves would have to yield the actual behavior of brightness perception in indirect vision. However, since one of the components has to do with stimuli, while the other has to do with perception, we have no right to combine the curves by simply adding their ordinates. However, we could imagine a curve which was constructed so that, if its ordinate were added to the corresponding one of the curve PQ, the result would be the same as that obtained from a suitable combination of the actual sensitivity curve with PQ. If the decrease in objective brightness is to be precisely counterbalanced by increased sensitivity, then,

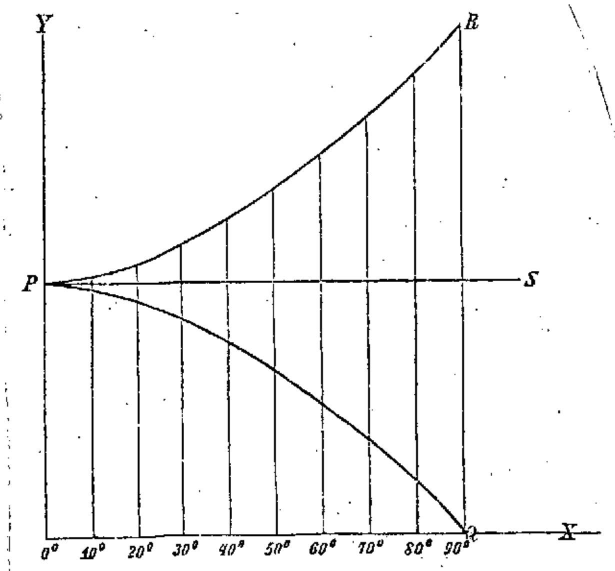

Fig. 3

since in this case the resultant representing the constant brightness effect over the entire retina would have to be depicted by the straight line PS, the line substituted for the actual sensitivity curve would have to be PR. The ordinates of this curve are related to the corresponding values of PQ by the ratio $1 - y:y$. Only then will the objective brightness decrease be nullified by the increase in sensitivity. On the other hand, if the curve PR follows a different course, the resultant will no longer be a horizontal straight line; i.e. brightness perception for a given object will differ at different points on the retina. It is very unlikely that the increase in sensitivity toward the periphery is precisely reflected by the curve PR. In every other case, the resultant differs more or less from PS. If the line representing the sensitivity increase has a lower curvature or is even a straight line intersecting the line PR, the resultant will be a curve line above PS. Accordingly, it would be likely that the sensitivity to intensities on the peripheral regions of the retina would be even greater than the compensation mentioned above, so that objects seen through parts surrounding the fovea centralis would have to look brighter than those perceived through the center itself. However, I will now attempt to demonstrate that this actually is the case.

1) It is a well-known fact, that very faint stars can be seen better by indirect vision than by fixation. Some astronomers make /456 practical use of this peculiarity, by intentionally seeking dim objects with the periphery of the retina. If the gradual appearance of stars at twilight is observed, one will usually not see them first in the center of the field of vision; they stand out best in indirect vision, and frequently a faint star will disappear when the attempt is made to fix upon it. The effects can only be explained by a greater sensitivity of the peripheral retina.

2) Slight nonuniformities in brightness and color on otherwise homogeneous surfaces and small rough spots on polished surfaces (the latter because of the distribution of light and shadow) are

detected better by indirect vision than by direct vision. If a spot of ink is covered with several sheets of translucent paper, it is easy to arrange it so that the spot will just disappear for central fixation, while it still can be faintly preceived by the side of the retina.

3) A similar effect can be observed in well-known experiments with Masson'sddisc. The white disc has on it a black line running in the radial direction and broken several times. If the disc is rotated, grey rings are produced, the interior rings being darker than the outer ones, since the black portion covers a larger angle. Therout-er rings become fainter and fainter toward the edge, and finally become completely invisible. This apparatus is frequently used to determine the discrimination threshold. Helmholtz [4] observed that the outer rings could be seen more clearly in these experiments if one did not fix upon them but instead let ones glance travel over the surrounding area. This is clear evidence for heightened light sensitivity in the retinal periphery.

4) After images are usually more distinct on the peripheral retinal than on the center. The best way to convince oneself of this is as follows. Two identical bright objects on a dark background /457 (or vice versa), some distance from one another, are viewed, one directly and the other indirectly. The afterimage of the object viewed indirectly will be found to be livelier and of longer duration.

If should be remarked that the after effects of light persist beyond the point at which the afterimage is no longer seen with eyes held opened or closed. Even when no trace of an afterimage can be detected any longer with the eyes opened or closed, the afterimage can be regenerated, in surprising intensity, by blinking, i.e. by rapidly opening and closing the eye. The afterimage is negative when the eye is open and positive when it is closed, but of very short duration in both cases, so that a persistent afterimage can be created only by very rapid blinking. In this way, already extinguished afterimages can be revived. In some cases, afterimages which disappeared

several minutes earlier can be recreated in this fashion. Accordingly, a peculiar state of "excitation inertia" appears to persist in the intensely illuminated parts of the retina for some time after the stimulus has ceased, judging by the fatigue of the retina indicated by the appearance of the negative afterimage. As a consequence of this "inertia", the perceiving elements of the excited points do not appear to switch back and forth between excitation and nonexcitation as fast as the surrounding regions. When the eye is closed, these elements darken later than the surrounding ones, and a positive after-image is retained for a moment. When the eye is opened, on the other hand, they are excited somewhat later than the other ones by the rays entering the eye from the background, thus creating a negative afterimage. It is not absolutely necessary that the alternation of light and darkness be produced by opening and closing the eyelids; the interruption can also be produced by a moderately rapidly rota- /458
ting episcotister. It is now easy to observe that these afterimages are produced more easily on the retinal periphery, and seem more lively; there is good reason to believe that the maximum of brightness sen-sitivity is in the periphery and not at the center of the retina.

5) The following experiment again demonstrates the higher sensi-tivity of the peripheral retina. If a bright object, such as a white cardboard disc, is viewed through a set of grey glasses -- or prefer-ably, colored ones, arranged so that together, they transmit only colorless light -- it is easy to choose the number and arrangement of glasses so that the object just disappears when fixed centrally; i.e. the small amount of light passing from it through the glasses into the eye is below the stimulus threshold. However, glancing to one side will cause the disc to reappear in indirect vision; evidence that the point on the retina now used does not need as great a stimulus in order to be excited.

6) Lastly, we should also remark that changes undergone by colors in indirect vision are not at all analogous to those induced in direct vision by reduction of brightness, but instead exhibit certain

similarities with the modifications in quality of light observed in direct vision when the intensity is raised. When the brightness is reduced (as at twilight), red becomes deep black, while in indirect vision it turns to orange, and remains roughly the same whether viewed against a dark or bright background. Neutral violet becomes grey when the brightness is even moderately reduced, while it appears blue in indirect vision.

These manifestations aroused in me the desired to determine more accurately the sensitivity of various parts of the retina by means of experiment. An added stimulus was the diversity of opinion on this /459 topic. While Charpentier and Aubert, along with most astronomers, assumed that light sensitivity was the same at all points of the retina and just changed in time by fatigue manifestations, other researchers even claimed that the center of the retina was more sensitive to light [4]. Schadow was the only one to study some points on the horizontal meridian and to find higher light sensitivity at the periphery ([5], p. 439 ff. Cf. Addendum for recent experiments of E. A. Fick). My work in the psychological seminar at Leipzig offered me an excellent chance to conduct the following investigation, since Prof. Wundt provided me with the space and equipment for the experiment and gave me very good advice. I will first describe the arrangement of the experiments.

It was explained above that the increased sensitivity of the peripheral retina not only counterbalanced the decrease in objective brightness of retinal images due to physical [geometrical] causes, but also brought about a state in which images on the peripheral regions had a higher intensity than those in the center, even subjectively. To determine this subjective increase in brightness quantitatively, a number of experiments using rotating discs were organized. These discs were made of cardboard and consisted of movable black and white sectors. Be shifting them, any stage of brightness between the white of the cardboard and the black dye (Paris Black) could be produced. The ratio of the brightness of the latter dye (which appears most suitable of all the black pigments for producing grey shades, because of its darkness) to the intensity of the white cardboard was found photometrically to be 1:66.

Diffuse daylight was used for illumination. The use of artifi- /460
cial illumination was rejected for two reasons: first to obtain illumination as colorless as possible (since, in colored light, the reduction of colors toward the periphery of the retina would interfere with a pure measurement of brightness sensitivity), and secondly to conduct the experiments under conditions as close as possible to the natural ones for using our organs of vision.

The experiments were carried out in a room with painted grey walls, which were lighted by three windows looking out onto a yard surrounded in turn by more or less colorless walls. The wall opposite the windows served as the background. The window shades were pulled down far enough to ensure that neither the observed object nor the background could receive direct light from the blue sky or from bright clouds.

The discs were attached to two rotating motors on a table some distance away from the evenly illuminated grey wall. In the experiments for the horizontal meridian of the eye, the motors were simply shifted along a straight line parallel to the background. (The unavoidable change in the apparent size of the object is quite small, since the observations were restricted to an angle of 30°, and cannot interfere with the experiment, since the size of the object is not of direct concern in this case.) Black silk threads were fastened to the base of the rotors, directly below the center of the discs. On the table of the observer, these threads crossed on a sharp vertical edge above the center of a protractor. Since the eye of the observer was at the same height as the center of the discs and was vertically above the vertex of the angle formed by the two threads, the angle between the objects in the field of vision could be read directly off the protractor. In experiments on vertical and slanted meridians, one of the rotors was attached to an iron support on which it could be moved, and the angle between the objects was then determined trigonometrically. /461

The procedure in these experiments was as follows: the observer closed one eye and fixed the other on the center of one of the two discs, focusing his attention on the indirectly viewed disc in order to compare the brightnesses. If the two discs were objectively identical, the one seen indirectly appeared brighter; then, the black part of the latter was increased until the brightnesses were subjectively the same. Since I went through this experiment with my own eyes, I usually did not start from the point of objective equality, but instead from an intensity which was too great or too small, and then changed the dark areas, without reading the size of the change in degrees (the degree scale was attached to the back of the discs), until subjective equality was obtained. In this case, naturally, the point of just-noticeable difference in either direction was ascertained and the arithmetic mean taken from these two values.

Before and after each experiment (i.e. for each change in the position of the devices), the discs were checked for subjective equality with identical sector settings, in order to keep track of the illumination. If, with both eyes, a point exactly halfway between the two objects was fixed, both discs should appear equally bright subjectively, as long as the illumination was uniform and the discs had the same objective setting.

The observer was 1.5 m from the fixed disc. The discs could not always be kept at the same distance from the background, since that was what regulated the relative brightness of the background. Namely, the discs were always placed so that the background had a brightness corresponding to a grey on the discs composed of 90° white and 270° black. In order to avoid detrimental contrast effects, it would be best to keep the relative brightness of the background as constant as possible; nevertheless the insignificant changes in distance between the wall and the discs occasioned by this procedure could have no appreciable influence on the estimation. In order to eliminate the possibility of high fatigue, the number of successive experiments was limited. There were no restrictions on eye movements between the individual observations. Since the observer had his back to the windows, this eliminated the possibility of interfering after-images, caused by conspicuous bright or dark objects in the room, as well as detrimental contrast effects of secondary type. Before each observation, care was take to ensure that no afterimages of the disc had been retained from a preceding experiment, the presence of which was easy to confirm by glancing around at the grey background.

TABLE I.
BACKGROUND = 270b + 90w; C = 180w + 180b.
DIAMETER OF THE DISCS 20 cm. DISTANCE FROM EYE 1.50 m.

Right Eye

	Outward			Inward		
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	172	$\frac{1}{23,2}$	1,045	172	$\frac{1}{23,2}$	1,045
$7\frac{1}{2}$	168	$\frac{1}{15,5}$	1,071	168	$\frac{1}{15,5}$	1,078
10	165	$\frac{1}{12,3}$	1,088	165	$\frac{1}{12,3}$	1,088
15	157	$\frac{1}{8}$	1,141	159	$\frac{1}{8,8}$	1,127
20	153	$\frac{1}{7}$	1,170	156	$\frac{1}{7,7}$	1,149

Left Eye

	Outward			Inward		
Angle	J	$\frac{C-J}{J}$	$\frac{C}{J}$	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	173	$\frac{1}{26,5}$	1,039	174	$\frac{1}{31}$	1,033
$7\frac{1}{2}$	168	$\frac{1}{15,5}$	1,078	170	$\frac{1}{18,5}$	1,057
10	162	$\frac{1}{10,3}$	1,107	165	$\frac{1}{12.3}$	1,088
15	158	$\frac{1}{8,5}$	1,134	161	$\frac{1}{9,8}$	1,114
20	152	$\frac{1}{6,6}$	1,178	157	$\frac{1}{8}$	1,141

TABLE II.

BACKGROUND = 270 b + 90 w. C = 150 w + 210 b.

Right Eye

	Outward			Inward		
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	J	$\frac{C-J}{C}$	$\frac{C}{J}$
$6\frac{1}{2}°$	144	$\frac{1}{26}$	1,040	144	$\frac{1}{26}$	1.040
10	139	$\frac{1}{14}$	1,077	137	$\frac{1}{12}$	1.091
$12\frac{1}{2}$	133	$\frac{1}{9}$	1,120	135	$\frac{1}{10.4}$	1,107
15	125	$\frac{1}{6,2}$	1,190	132	$\frac{1}{8.6}$	1.131
20	118	$\frac{1}{5}$	1,259	128	$\frac{1}{7}$	1,164
25				125	$\frac{1}{6.2}$	1.191

Left Eye

	Outward			Inward		
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	J	$\frac{C-J}{C}$	$\frac{C}{J}$
$6\frac{1}{2}°$	144	$\frac{1}{26}$	1,040	145	$\frac{1}{38}$	1.033
10	140	$\frac{1}{18,6}$	1,069	138	$\frac{1}{14}$	1,084
$12\frac{1}{2}$	135	$\frac{1}{10.4}$	1.107	136	$\frac{1}{11.1}$	1.099
15	126	$\frac{1}{6,5}$	1,182	131	$\frac{1}{8}$	1,139
20	119	$\frac{1}{5}$	1.259	129	$\frac{1}{7,5}$	1,156
25				127	$\frac{1}{6.8}$	1,173

In the attached tables, the first column represents the angle /462 between the objects in the field of vision. The second column, headed by J, is the sector ratio. For simplicity, only the size of the white sector is given, from which it is easy to determine the angle of the black sector (= 360° - J). C represents the constant, fixed disc, while J represents the one viewed indirectly, the brightness of which is changed until subjective equality is achieved. The fraction C/J in the last column can be considered a direct measure of the

TABLE III.

BACKGROUND = 90 w + 270 b. C = 120 w + 240 b.

Right Eye

	Outward			Inward		
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	J	$\frac{C-J}{C}$	$\frac{C}{J}$
7°	112	$\frac{1}{15.7}$	1.068	112	$\frac{1}{15.7}$	1.068
10	105	$\frac{1}{8.9}$	1.136	108	$\frac{1}{10.5}$	1.106
12½	100	$\frac{1}{6.3}$	1.189	105	$\frac{1}{8.9}$	1.136
15	96	$\frac{1}{5.23}$	1.236	102	$\frac{1}{7}$	1.168
17½	—	—	1.000	100	$\frac{1}{6.3}$	1.189
20	93	$\frac{1}{4.6}$	1.274	98	$\frac{1}{5.3}$	1.212
22½	94	$\frac{1}{4.8}$	1.260	98	$\frac{1}{5.3}$	1.212
25	96	$\frac{1}{5.23}$	1.236	101	$\frac{1}{6.6}$	1.178

Left Eye

	Outward			Inward		
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	J	$\frac{C-J}{C}$	$\frac{C}{J}$
7°	113	$\frac{1}{18}$	1.059	113	$\frac{1}{18}$	1.059
10	107	$\frac{1}{9.66}$	1.116	108	$\frac{1}{10.5}$	1.106
12½	102	$\frac{1}{7}$	1.168	106	$\frac{1}{9}$	1.126
15	97	$\frac{1}{5.46}$	1.224	103	$\frac{1}{7.4}$	1.157
17½	95	$\frac{1}{5}$	1.249	101	$\frac{1}{6.6}$	1.178
20	92	$\frac{1}{4.5}$	1.287	100	$\frac{1}{6.3}$	1.189
22½	95	$\frac{1}{5}$	1.249	100	$\frac{1}{6.3}$	1.189
25	97	$\frac{1}{5.5}$	1.224	101	$\frac{1}{6.6}$	1.178

sensitivity of the retinal point concerned. A more illuminating parameter is the ratio (C - J)/C shown in the third column, which shows the fraction of the brightness of the fixed disc which the one viewed indirectly can give up and still appear just as bright

TABLE IV.
BACKGROUND = 270 b + 90 w. C = 180 w + 180 b. DISTANCE 1.50 m; DIAMETER OF DISCS 13 cm.

Left Eye								Right Eye							
Outward				Inward				Outward				Inward			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	176	$\frac{1}{46.4}$	1,022	5°	175	$\frac{1}{37.1}$	1,028	5°	175	$\frac{1}{37.1}$	1,028	5°	174	$\frac{1}{31}$	1,033
$7^1/_2$	172	$\frac{1}{23.2}$	1,045	$7^1/_2$	172	$\frac{1}{23.2}$	1,045	$7^1/_2$	172	$\frac{1}{23,2}$	1.045	$7^1/_2$	170	$\frac{1}{18.5}$	1,037
10	168	$\frac{1}{15.5}$	1,078	10	169	$\frac{1}{16.8}$	1.063	10	167	$\frac{1}{14,3}$	1,075	10	166	$\frac{1}{13.2}$	1.052
$12^1/_2$	165	$\frac{1}{12.3}$	1,088	$12^1/_2$	167	$\frac{1}{14.3}$	1,075	$12^1/_2$	164	$\frac{1}{11,6}$	1.094	$12^1/_2$			
15	162	$\frac{1}{10.3}$	1,107	15				15	160	$\frac{1}{9.3}$	1,121	15			
$17^1/_2$	159	$\frac{1}{8.8}$	1,127	$17^1/_2$	166	$\frac{1}{13.2}$	1.082	$17^1/_2$	158	$\frac{1}{8,5}$	1.134	$17^1/_2$	164	$\frac{1}{11.6}$	1,094
20	156	$\frac{1}{7.7}$	1,149	20	164	$\frac{1}{11.6}$	1,094	20	156	$\frac{1}{7,7}$	1,149	20	162	$\frac{1}{10.3}$	1,107
$22^1/_2$	155	$\frac{1}{7,1}$	1,156	$22^1/_2$	162	$\frac{1}{10.3}$	1,107	$22^1/_2$	156	$\frac{1}{7,7}$	1.149	$22^1/_2$	160	$\frac{1}{9.3}$	1,121
25	156	$\frac{1}{7.7}$	1,149	25	160	$\frac{1}{9.3}$	1,121	25	158	$\frac{1}{8.5}$	1,134	25	158	$\frac{1}{8.5}$	1,134
30	160	$\frac{1}{9.3}$	1,121	30	164	$\frac{1}{11.6}$	1,094	30	160	$\frac{1}{9,3}$	1,121	30	162	$\frac{1}{10.3}$	1,107

Top				Bottom				Top				Bottom			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5° 4′	177	$\frac{1}{61.8}$	1.016	5° 4′	176	$\frac{1}{46.4}$	1,022	5° 4′	177	$\frac{1}{61.8}$	1.016	5° 4′	177	$\frac{1}{61,3}$	1,016
6 24	176	$\frac{1}{46.4}$	1.022	6 6	175	$\frac{1}{37.1}$	1,028	6 24	176	$\frac{1}{46,4}$	1.022	6 6	176	$\frac{1}{46,4}$	1,022
7 47	176	$\frac{1}{46.4}$	1,022	7 36	173	$\frac{1}{26.6}$	1,039	7 47	176	$\frac{1}{46.4}$	1,022	7 36	174	$\frac{1}{31}$	1,033
9 1	174	$\frac{1}{31}$	1,033	9 17	172	$\frac{1}{23.2}$	1.045	9 1	175	$\frac{1}{37,1}$	1,028	9 17	173	$\frac{1}{26,6}$	1,039
10 45	172	$\frac{1}{23.2}$	1,045	11 18	171	$\frac{1}{20.7}$	1.051	10 45	173	$\frac{1}{26,6}$	1,039	11 18	172	$\frac{1}{23.2}$	1,045
12 35	173	$\frac{1}{26.6}$	1,039	13 8	170	$\frac{1}{18.5}$	1.037	12 35	174	$\frac{1}{31}$	1.033	13 18	171	$\frac{1}{20,7}$	1,051
14 35	174	$\frac{1}{31}$	1,053	15 13	172	$\frac{1}{23.2}$	1.045	14 35	175	$\frac{1}{37,1}$	1,028	15 13	173	$\frac{1}{26,6}$	1,039

as the one viewed directly.

In the experiments listed in Tables I and II, I used two discs 20 cm in diameter, while smaller discs about 13 cm in diameter were

TABLE V-A.
BACKGROUND = 90 w + 270 b; C = 270 w + 90 b; DISTANCE 1.50 m.
DIAMETER OF DISCS 13 cm.
LEFT EYE

ORIGINAL PAGE IS
OF POOR QUALITY

Outward				Inward			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	266	$\frac{1}{68.8}$	1,105	5°	265	$\frac{1}{56.7}$	1.018
6	265	$\frac{1}{56.7}$	1,018	6	263	$\frac{1}{39.4}$	1.026
7½	262	$\frac{1}{34.4}$	1.03	7½	260	$\frac{1}{27.6}$	1.038
10	258	$\frac{1}{23}$	1.046	10	257	$\frac{1}{21}$	1.05
12½	255	$\frac{1}{18.5}$	1.058	12½	252	$\frac{1}{15.3}$	1.07
15	252	$\frac{1}{15.3}$	1.07	15			
17½	249	$\frac{1}{13.1}$	1.083	17½	250	$\frac{1}{13.8}$	1.078
20	246	$\frac{1}{11.5}$	1.095	20	248	$\frac{1}{12.6}$	1.087
22½	248	$\frac{1}{12.6}$	1,087	22½	246	$\frac{1}{11.5}$	1,095
25	250	$\frac{1}{13.8}$	1,078	25	246	$\frac{1}{11.5}$	1,095
30	252	$\frac{1}{15.3}$	1.07	30	248	$\frac{1}{12.6}$	1.087

Top-outer				Bottom-Inner			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5° 4′	265	$\frac{1}{56.7}$	1,018	5° 4′	267	$\frac{1}{91.8}$	1,011
6 28	263	$\frac{1}{39.4}$	1,026	6 28	265	$\frac{1}{56.7}$	1.018
8 10	361	$\frac{1}{24.5}$	1,034	8 10	261	$\frac{1}{29.5}$	1.034
9 39	256	$\frac{1}{19.7}$	1,054	9 39	259	$\frac{1}{23}$	1.046
11 41	249	$\frac{1}{13.1}$	1,083	11 41	256	$\frac{1}{19.7}$	1,054
13 45	248	$\frac{1}{12.6}$	1,087	13 45	258	$\frac{1}{23}$	1.046
15	246	$\frac{1}{11.5}$	1,095	15	255	$\frac{1}{18.5}$	1.058

Top				Bottom			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5° 8′	264	$\frac{1}{46}$	1,022	5° 8′	266	$\frac{1}{68.8}$	1,015
6 24	262	$\frac{1}{34.4}$	1.03	6 24	265	$\frac{1}{56.7}$	1.018
7 58	260	$\frac{1}{27.6}$	1.038	8 10	263	$\frac{1}{39.7}$	1.026
9 17	258	$\frac{1}{23}$	1.046	9 57	260	$\frac{1}{27.5}$	1.038
10 55	260	$\frac{1}{27.6}$	1.038	11 41	260	$\frac{1}{27.5}$	1.038
12 57	255	$\frac{1}{18.5}$	1,058	13 30	258	$\frac{1}{23}$	1.046
15 13	257	$\frac{1}{21}$	1.05	15 30			

Bottom-Outer				Top-Inner			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5° 4′	266	$\frac{1}{68.8}$	1.015	5° 4′	264	$\frac{1}{46}$	1,022
6 28	264	$\frac{1}{46}$	1.022	6 28	262	$\frac{1}{34}$	1.03
8 10	260	$\frac{1}{27.6}$	1.038	8 10	260	$\frac{1}{27.6}$	1,038
9 39	262	$\frac{1}{34}$	1.03	9 39	257	$\frac{1}{21}$	1.05
11 41	257	$\frac{1}{21}$	1.05	11 41	252	$\frac{1}{15.3}$	1.07
13 45	255	$\frac{1}{18.5}$	1.058	13 45	253	$\frac{1}{16.2}$	1,066
15	252	$\frac{1}{15.3}$	1.07	15	251	$\frac{1}{14.5}$	1,074

used in later experiments. In Experiments I through III, the angles were never larger than 25°. While further observations were made, they seemed too uncertain to include in the tables. In general, /474

TABLE V-B.
BACKGROUND = 90 w + 270 b; C = 270 w + 90 b. DISTANCE 1.50 m.
DIAMETER OF DISCS 13 cm.
RIGHT EYE

Outward				Inward			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	266	$\frac{1}{68.8}$	1,015	5°	265	$\frac{1}{56.7}$	1,018
6	265	$\frac{1}{56.7}$	1,018	6	263	$\frac{1}{39.4}$	1,026
$7\frac{1}{2}$	262	$\frac{1}{34.4}$	1.03	$7\frac{1}{2}$	260	$\frac{1}{27.6}$	1,038
10	257	$\frac{1}{21}$	1.05	10	256	$\frac{1}{19.7}$	1,054
$12\frac{1}{2}$	254	$\frac{1}{17.2}$	1.062	$12\frac{1}{2}$	253	$\frac{1}{16.2}$	1.066
15	250	$\frac{1}{13.8}$	1.078	15			
$17\frac{1}{2}$	248	$\frac{1}{12.6}$	1,087	$17\frac{1}{2}$	253	$\frac{1}{16.2}$	1,066
20	245	$\frac{1}{11}$	1.1	20	248	$\frac{1}{12.6}$	1.087
$22\frac{1}{2}$	248	$\frac{1}{12.6}$	1.087	$22\frac{1}{2}$	245	$\frac{1}{11}$	1.1
25	250	$\frac{1}{13.8}$	1,078	25	244	$\frac{1}{10.6}$	1.104
30	250	$\frac{1}{13.8}$	1,078	30	246	$\frac{1}{11.5}$	1,095

Top				Bottom			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5° 8′	266	$\frac{1}{68.8}$	1,015	5° 8′	267	$\frac{1}{91.8}$	1.011
6 24	264	$\frac{1}{46}$	1,022	6 24	266	$\frac{1}{68.8}$	1,015
7 58	261	$\frac{1}{29.5}$	1,034	8 10	265	$\frac{1}{56.7}$	1,018
9 17	258	$\frac{1}{23}$	1,046	9 57	261	$\frac{1}{46}$	1,022
10 55	256	$\frac{1}{19.7}$	1.054	11 41	262	$\frac{1}{34.4}$	1.03
12 57	253	$\frac{1}{16.2}$	1,066	13 30	262	$\frac{1}{34.4}$	1,03
15 13				15 30	260	$\frac{1}{27.6}$	1,038

Top-Outer				Bottom-Inner			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5° 4′	266	$\frac{1}{68.8}$	1,015	5° 4′	267	$\frac{1}{91.8}$	1,011
6 28	264	$\frac{1}{46}$	1,022	6 28	263	$\frac{1}{39.4}$	1,026
8 10	259	$\frac{1}{25}$	1.042	8 10	259	$\frac{1}{25}$	1,042
9 39	252	$\frac{1}{15.3}$	1,07	9 39	256	$\frac{1}{19.7}$	1,054
11 41	254	$\frac{1}{17.2}$	1,062	11 41	250	$\frac{1}{13.8}$	1.078
13 45	254	$\frac{1}{17.2}$	1,062	13 45	247	$\frac{1}{12}$	1,091
15	250	$\frac{1}{13.8}$	1.078	15	250	$\frac{1}{13.8}$	1,078

Bottom-Outer				Top-Inner			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5° 4′	266	$\frac{1}{68.8}$	1,015	5° 4′	265	$\frac{1}{56.7}$	1,018
6 28	266	$\frac{1}{68.8}$	1,015	6 28	263	$\frac{1}{39.4}$	1,026
8 10	263	$\frac{1}{39.4}$	1,026	8 10	258	$\frac{1}{23}$	1.046
9 39	260	$\frac{1}{27.6}$	1,038	9 39	253	$\frac{1}{16.2}$	1,066
11 41	258	$\frac{1}{23}$	1,046	11 41	250	$\frac{1}{12.8}$	1.078
13 45	259	$\frac{1}{25}$	1,042	13 45	247	$\frac{1}{12}$	1.091
15	259	$\frac{1}{25}$	1,042	15	249	$\frac{1}{13.2}$	1.083

it seemed as if sensitivity to brightness began to decrease again above 25° so that the maximum of brightness sensitivity on the horizontal meridian appears to be about 22°-25° from the center, and this

TABLE VI.
BACKGROUND = 270° + 90 w. C = 330 w + 30 b. DISTANCE 1.50 m.

Left Eye

Outward				Inward			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	326	$\frac{1}{81}$	1.012	5°	326	$\frac{1}{84}$	1.012
6	324	$\frac{1}{56}$	1.018	6	322	$\frac{1}{42}$	1.025
7½	322	$\frac{1}{42}$	1.025	7½	320	$\frac{1}{33.5}$	1.031
10	320	$\frac{1}{33.5}$	1.031	10	316	$\frac{1}{24}$	1.044
12½	317	$\frac{1}{25.8}$	1.043	12½	314	$\frac{1}{21}$	1.05
15	316	$\frac{1}{24}$	1.044	15			
17½	314	$\frac{1}{21}$	1.05	17½	311	$\frac{1}{17.7}$	1.06
20	311	$\frac{1}{17.7}$	1.06	20	308	$\frac{1}{15.3}$	1.07
22½	308	$\frac{1}{15.3}$	1.07	22½	306	$\frac{1}{14}$	1.077
25	311	$\frac{1}{17.7}$	1.06	25	302	$\frac{1}{11.9}$	1.091
30	312	$\frac{1}{18.6}$	1.057	30	304	$\frac{1}{12.9}$	1.084

Right Eye

Outward				Inward			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	326	$\frac{1}{81}$	1.012	5°	325	$\frac{1}{67.1}$	1.015
6	322	$\frac{1}{42}$	1.025	6	323	$\frac{1}{48}$	1.021
7½	319	$\frac{1}{30.5}$	1.034	7½	320	$\frac{1}{33.5}$	1.031
10	316	$\frac{1}{24}$	1.044	10	318	$\frac{1}{28}$	1.037
12½	314	$\frac{1}{21}$	1.05	12½	315	$\frac{1}{22.4}$	1.047
15	311	$\frac{1}{17.7}$	1.06	15			
17½	309	$\frac{1}{16}$	1.067	17½	308	$\frac{1}{15.3}$	1.07
20	306	$\frac{1}{14}$	1.077	20	305	$\frac{1}{13.4}$	1.081
22½	304	$\frac{1}{12.9}$	1.084	22½	303	$\frac{1}{12.4}$	1.088
25	306	$\frac{1}{14}$	1.077	25	303	$\frac{1}{12.4}$	1.088
30	306	$\frac{1}{14}$	1.077	30	305	$\frac{1}{13.4}$	1.081

Left Eye

Top				Bottom			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	326	$\frac{1}{84}$	1.012	5°	327	$\frac{1}{112}$	1.009
6½	322	$\frac{1}{42}$	1.025	6½	323	$\frac{1}{48}$	1.021
8½	318	$\frac{1}{28}$	1.037	8½	322	$\frac{1}{42}$	1.025
9½	313	$\frac{1}{19.7}$	1.053	9½	320	$\frac{1}{33.5}$	1.031
12	313	$\frac{1}{19.7}$	1.053	12	320	$\frac{1}{33.5}$	1.031
14¼	314	$\frac{1}{21}$	1.05	14¼			

Right Eye

Top				Bottom			
Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	J	$\frac{C-J}{C}$	$\frac{C}{J}$
5°	326	$\frac{1}{84}$	1.012	5°	327	$\frac{1}{112}$	1.009
6½	323	$\frac{1}{48}$	1.021	6½	324	$\frac{1}{56}$	1.018
8½	319	$\frac{1}{30.5}$	1.034	8½	323	$\frac{1}{48}$	1.021
9½	316	$\frac{1}{24}$	1.044	9½	321	$\frac{1}{37.3}$	1.028
12	314	$\frac{1}{21}$	1.05	12			
14¼	318	$\frac{1}{28}$	1.037	14¼			

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was confirmed by further experiments (Tables IV, V, and VI).

Once experiments I through III had shown that the sensitivity to colorless light actually does increase toward the periphery, it became necessary to study this change in the direction of the vertical meridian as well. Therefore, in Table IV results are shown for observations in the vertical direction. The terms "outwards", "inwards," "top", and "bottom" refer to the retina itself, and not to the field of vision, a notation to be retained in later series. The fact that the angles on the vertical meridian were given in degrees and minutes is due to the fact that the angles were measured trigonometrically, and no longer by the protractor. A surprising result was obtained from these experiments, namely that the increase in brightness both upward and downward was far less than that in the direction of the horizontal meridian. The experiments could not be extended beyond an angle of 15° toward the top and bottom, since it was no longer possible to reach a reliable verdict at greater angles; the sensitivity did not continue to increase, instead appearing to decrease slightly, so that the maximum sensitivity is probably at about 12-15°.

In Table V, studies on the horizontal and vertical meridian are supplemented by an investigation of the meridian inclined at 45°. In order to conduct these experiments as accurately as possible, a cross hairs corresponding to the meridian directions was attached to the background wall; these rotors were then shifted so that the centers of the discs, seen from the point of the observer's eye always coincided with the cross hairs. The subtended angle had to be kept calculated in these experiments as well, since only the linear separation could be measured directly.

In Fig. 4, which goes with Table V, I have tried to illustrate /475
the situation. The diagram represents a central projection of the field of vision of both eyes on the plane. The upper half of the circles corresponds to the lower half of the retina, and other half of the projection to the nasal side of the eye, etc., as indicated by the accompanying letters (a = outside, i = inside, v = top, u = bottom). Points of equal sensitivity on the four meridians studied were connected by lines. This connection was made by curves, and not straight lines, because the latter method would result in very

distorted figures because of the small number of meridians investigated. This would have diminished the clarity of the diagrams without coming any closer to the truth than our interpolation with arcs.

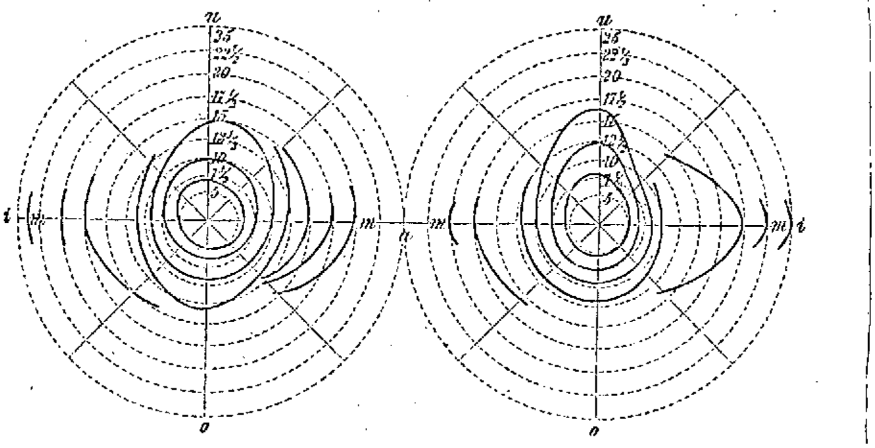

Fig. 4.

The inner circle designates the points on the retina with a sensitivity equal to 1.018 (C/J) according to the tables; the second closed curve corresponds to a sensitivity of 1.03; and the third to 1.046. The fourth curve is no longer closed, since the lower parts of the retina do not attain this sensitivity. The corresponding /476 equivalents are missing on both the top and the bottom for the succeeding curves, so that the curve is broken into two separate parts. The direction of these segments is noteworthy, since if they were extrapolated, they would intersect the vertical meridian at points which obviously did not have the same sensistivity as the corresponding parts on the other two meridians. If the maximum points on all meridians, regardless of magnitude, are linked up, the result is a more or less elliptical curve (not drawn in any diagram).

From the projection it can be seen that the increase in sensitivity in the horizontal direction is much greater than that in the vertical, and that the sensitivity of the upper half of the retina rises faster than that of the lower half. This situation is quite consistent with the actual requirements of our organs of vision, and can therefore be viewed as altogether appropriate and probably achieved by self-regulation of visual processes.

The position of objects in space, with which we are dealing and to which we must direct our attention, implies that the indirect visual sensations received by the sides of the retina will be more important for us than indirect vision with the upper and lower regions. And furthermore, with regard to the different sections of the vertical meridian, it is easy to see that the importance of the lower half will be subordinate to that of the upper half. When we are looking straight ahead during work or motion, there will be a large number of objects below the horizon to keep in mind, although not to fix upon; above the horizon, on the other hand, there will usually be only remote objects, extended by areas such as the sky, or the bright ceiling of a room. Therefore, if those parts of the retina which correspond to these usually bright parts of the field of vision were equipped with a sensitivity similar to that of the horizontal meridian, which appeared appropriate in that case, it would therefore just interfere in the function of the sense of sight.

At first glance, it must appear very peculiar and contradictory /478 that the values for the sensitivity of the points on the retinas studied were not the same for the different factor ratios employed. As a summary, I have collected the maximum of the sensitivities for the horizontal meridian in Table VII. It is true that the maximum sensitivity always occurs 20-25° away from the center, but if the discs were not as bright, so that the difference between background and disc was not as great as when the intensity of the discs was higher, the sensitivity obviously appears to be relatively larger. At first glance, this appears to be a direct contradiction. However, it should be kept in mind that the background affects the sides differently from the central part. Since the background is a continuous surface, we are not aware of the gradual transition to more intense sensation, just as we think we are seeing the entire surface red when we look at

TABLE VII

TABULATION OF BRIGHTNESS MAXIMA FROM SERIES II THROUGH VI.

Left Eye

Sector Ratio of C	Brightness of C	Outward			Inward		
		Angle	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	$\frac{C-J}{C}$	$\frac{C}{J}$
120 w + 240 b	$22^2/_3$	20°	$\frac{1}{4.5}$	1,287	20—$22^1/_2$°	$\frac{1}{6.3}$	1,189
150 w + 210 b	$28^1/_3$	20	$^1/_5$	1,259	25	$\frac{1}{6.8}$	1,173
180 w + 180 b	$33^1/_2$	$22^1/_2$	$\frac{1}{7.1}$	1,156	25	$\frac{1}{9.3}$	1,121
270 w + 90 b	$49^3/_4$	20	$\frac{1}{11.5}$	1,095	$22^1/_2$—25	$\frac{1}{11.5}$	1,095
330 w + 30 b	$60^1/_{12}$	$22^1/_2$	$\frac{1}{15.3}$	1,07	25	$\frac{1}{11.9}$	1,091

Right Eye

Sector Ratio of C	Brightness of C	Outward			Inward		
		Angle	$\frac{C-J}{C}$	$\frac{C}{J}$	Angle	$\frac{C-J}{C}$	$\frac{C}{J}$
120 w + 240 b	$22^2/_3$	20°	$\frac{1}{4.6}$	1,274	20—$22^1/_2$°	$\frac{1}{5.3}$	1.212
150 w + 210 b	$28^1/_3$	20	$^1/_5$	1,259	25	$\frac{1}{6.2}$	1,191
180 w + 180 b	$33^1/_2$	20—$22^1/_2$	$\frac{1}{7.7}$	1,149	25	$\frac{1}{8.5}$	1,134
270 w + 90 b	$49^3/_4$	20	$\frac{1}{11}$	1,1	25	$\frac{1}{10.6}$	1,104
330 w + 30 b	$60^1/_{12}$	$22^1/_2$	$\frac{1}{12.9}$	1,084	$22^1/_2$—25	$\frac{1}{12.4}$	1,088

1) Background = 270 b + 90 w = 17 1/4 (b = 1; w = 66).

a large uniform red surface, although in fact most of the retina cannot detect red at all. However, if the continuity of the surface is disrupted, we immediately notice that the parts seen indirectly just appear yellow. The fact that this brightness relationship is reversed when the discs are darker when the background is evidence that a similar effect occurs in brightness perception, namely that a uniformly illuminated background exerts a stronger influence on the side of the retina, but the change is not large and abrupt enough to be noticed. For instance, an experiment was conducted with two identical completely black discs, and the one not fixed upon appeared considerably darker. At the outset, I did not rule out the possibility of an illusion, I had quite impartial persons, who were not informed about the organization and purpose of the studies, make the same observations; they had exactly the same sensation: the indirectly seen disc was thought /479 to be darker. This can only be a consequence of the fact that the background appears brighter in indirect vision, so that the black of the indirectly viewed disc (= 1/66 white) is darkened more by contrast than the fixed one. An attempt to measure the degree of this darkening for specific separations had to be abandoned, since the addition of white which would have been necessary in order to restore subjective equality proved to be too small to be measured with our devices. If the background and discs were equal in brightness, the indirectly seen disc was nevertheless considered "brighter", since the discs could not be made to blend completely into the background, perhaps because of extremely small color differences or for undetermined reasons. Again, of course, quantitative determination was not feasible.

Judging from what has been said already, it is virtually certain that the contrast brought about by the background played an essential role in the other series as well. When the maxima recorded in Series VI are compared, a constant increase in sensitivity paralleling the decrease in absolute brightness is found, and this can only be explained as an effect of the contrast between the objects and the background. As was demonstrated in the experiments of Lehmann [6], the brightness contrast does not increase without limit as a function of the difference between the contrasting intensities, but reaches a maximum at a certain median brightness difference. Consequently, a very bright disc, e.g. a totally white one can no longer produce such a vivid contrast as one which is less bright. Assuming that the laws established by Lehmann and Neiglick for brightness contrast also apply to the side of the retina, it is easy to see that when the brightness difference between the background and the object is less than the difference corresponding to the maximum contrast, the conditions for

maximum contrast brightening must be more favorable for the indirectly viewed disc than for the fixed one. On the other hand, once the /480
maximum difference has been exceeded, the central disc will have a distinct advantage. This is then the explanation for the fact that the experiments with brighter discs yielded lower values for brightness sensitivity, inasmuch as the contrast counteracted it, while it promoted it in experiments with darker discs. However, the temptation to apply Lehmann's values to our experiments must be resisted, for the following reasons: first, we cannot a priori assume that the maximum differences from Lehmann are also valid for the side of the retina; moreover, Lehmann's experiments were conducted by yellow lamplight, while mine were carried out in daylight. Finally, there is a purely psychological factor which must not be ignored in all contrast judgments in my opinion: the comparison with objects unrelated to the experiment but nevertheless in the field of vision.

As mentioned earlier, contrast is greatest at a moderate brightness. If the brightness is increased, the contrast drops off, since the brightening of an object which is already very bright anyway cannot be very substantial. In a certain sense, the intensity to be judged approaches a brightness maximum at which no contrast brightening at all is possible. However, this brightness maximum is not an absolute one, but determined by the surroundings of the observer, so that the brightest object in the field of vision tend to represent the applicable brightness maximum or at least approach it very closely. It is this circumstance which makes it so easy for us to believe ourselves in a real situation when viewing pictures, panoramas, transparent stereoscopes, etc. Even when brightly illuminated, a painted black wall looks black to us. However, if we look at it through a tube painted black on the inside, it no longer appears black; in fact, if we do not know it is a "black" wall, it can even give the impression of white. Contrast plays only a minor role in /481
this effect, the latter being due primarily to the above mentioned property of our sense of sight, namely that we construct a type of

brightness maximum based on the intensities of colorless light present in our field of vision, and this brightness maximum places limits on the brightening due to contrast. A sheet of white paper or a painted white wall are usually so close to the brightness maximum that we cannot bring about appreciable brightening of these objects by any kind of contrast effect. If, however, near the white wall or paper, there is freshly fallen snow, which presents a much brighter and purer white to the eye than paper or paint, the latter will experience contrast brightening, since we have now shifted our own brightness maximum by a considerable amount. A similar situation prevails in the assessment of saturation and purity of color. A pigment can make an impression of great saturation and purity in our eye as long as the same color in greater saturation and more complete purity is not available nearby as a comparison. In the latter case, the original pigment will appear displaced to lower rung on the ladder of purity and saturation, at which point it can again be raised by contrast, although this could not occur without the existence of the comparison.

In the present case, this effect, which is based on purely psychological processes and must be distinguished from adaptation due to physiological conditions, has the result that in experiments with very bright discs (270 w + 90 b and 330 w + 30 b) the brightening could not be very great (strict attention was paid to keeping brighter objects out of the field of vision); its effect was less on the peripheral retina, where the subjective brightness was greater, than in the center of the field of vision. Hence, Series V and VI were those least affected by contrast, and the numbers found in these experiments should be closest to the actual values for brightness sensitivity, while the high values in Series I, II, and III are probably the consequence of intensification due to contrast. For /482
this reason, the experiments in Series V were carried out on four different meridians. Hence, Series V seemed to be the most suitable for a graphic representation, as given in Fig. 4. However, it should

not be forgotten that the influence of contrast can never be completely eliminated in experiments dealing with differences with intensity.

At this point, it should also be mentioned that shifting the interior fixation point, as would have been expected, did not cause the pupil to dilate or contract. This was established by several experiments using the phacoscope, conducted with the aid of Dr. Külpe, the assistant of the Psychological Institute assisting me with valuable advice and support in the studies. The eye of the observer looked toward a rectagular opening, roughly 1 square inch in area, through which shown the light of a lamp. By drawing back a slide, a bright point was made visible in the side of the field of vision, a point which was so small that its brightness did not add significantly to the amount of light coming through the slit to the eye. Its sudden appearance caused the observer to shift his attention toward this point in the field of vision. Neither at the moment at which this occurred, nor later, could Dr. Külpe detect any change in pupil width in my eye. I then repeated the experiment on Dr. Külpe's eye, with the same result. Not even the slightest change in size or position of cornea and lens images could be discovered either. Thus, there is no reason to fear that the results of the above investigations might be impaired by neglecting some change in the eye's equipment for regulating the admission of light and of accommodation.

In the studies on the verical meridian, binocular observation /483
was also employed as an experiment; the uncertainty of the estimate increased in striking fashion. An interesting phenomenon, which should not be omitted from this discussion, occurred during binocular observation when the discs were about 30-40 cm apart. The indirectly viewed objects sometimes disappeared, so completely that the observer thought he saw only the background. This disappearance became even more mysterious when it was found that monocular observation did not give rise to any such effect, even when the discs were further apart.

Therefore, I attempted to determine the duration of the disappearance using a pressure chronometer giving readings accurate to within

1/5 sec. When several series of ten experiments each were conducted, I found that the period of disappearance lasted for 1.1-1.2 seconds in the upper field of vision, and 1.6-1.8 seconds in the lower field of vision. The intervals between the different interruptions appeared to be quite irregular.

Professor Wundt, whom I informed of this phenomenon, explained it in the following fashion: with the given arrangement of the objects and the given position of the eyes, the indirectly viewed disc is not located in the horopter, so that the images will not coincide completely. Hence, there will be transition zones on either side of the image (in a transition zone, one eye will see the background and the other the disc) which facilitate blending in with the background, while the continuing (although unconscious) effort to make the images coincide will silumtaneously induce eye fatigue earlier than usual.

A second no less striking phenomenon, which has received no attention in the relevant literature as far as I know, should not remain unmentioned. If a disc made up of black and white sectors is rotated just fast enough in lamplight or shaded daylight to make the black and white blend into a homogeneous grey, this speed of rotation will no longer be sufficient in brighter illumination, e.g. a magnesium light or bright daylight. This is not the place to /484
delve into the causes of this behavior. The only point of interest for our present discussion is the fact that precisely the same thing occurs when the disc is observed at constant illumination in indirect vision, as opposed to increased illumination in direct vision. If the rotation rate is just sufficient to cause blending into homogeneous grey when the eye is fixed on the disc, a perceptible flickering will be observed when the object is removed from the center of vision. The greater the displacement of the image from the center, the greater the flickering.

A disc rotates slowly so that it still flickers somewhat in central fixation, the flickering will be enhanced in indirect vision.

It will seem as if the sectors, which are seen almost individually, move much more slowly than they actually do. Upon looking back at the disc, one will be astonished to see the disc still rotating rapidly, since it seemed almost to be standing still in indirect vision.

At the outset, I suspected that the peculiar behavior of the peripheral retina could be ascribed to abnormal excitation states of my own eye, perhaps due to the numerous fatiguing experiments. Therefore, I employed persons not trained in indirect vision for same experiments. These people made precisely the same observations. Some experiments with colored discs provided further confirmation. In direct vision, a disc made up of ultramarine blue and orange sectors became a homogeneous violet at a certain rate of rotation. Nevertheless, in indirect vision, a distinct flickering could be observed, and if the object was moved further from the center of the field of vision, the orange and blue components could be separated.

In order to study this interesting effect more precisely, I used a rotor consisting of a drum about 20 cm high rotating on a vertical axis. The drum could be set in motion by a spring. A wind vane regulated the speed of rotation. An automatic lever caused a /485
noise at each rotation, and this made it easy to count the rotations; fractions of rotation could be read off a circular scale. The drum was covered with nonshiny black paper, on which were drawn 137 vertical white lines 1 1/3 mm wide and 2 2/3 apart. The black of the background corresponded to a sector ratio of 353 b + 7 w of the discs described above. The grey produced by faster rotation of the drum was the same as a grey produced by a disc made up of 287 b + 82 w. A simple calculation shows that the brightness of the black background was related to the white lines by the ratio 1:20.

In front of this drum, there was a black cardboard screen with a square opening 3 1/2 cm on the side. Now, either the opening itself or a point to one side was fixed, and the rate of rotation of the device adjusted until the part of the drum surface visible behind the opening blended into a homogeneous grey.

In these experiments, in which Dr. Külpe was good enough to assist me, the following procedure was employed: the eye of the observer was precisely 50 cm away from the opening, and was first fixed upon the center of the opening; then the device was rotated fast enough to make the black and white stripes blend into a uniform grey. Once this had been done, the speed of the device was determined using a chronometer. Now the eye of the observer was fixed on a point a to one side of the opening, while the observer's attention was still directed at the opening itself. The speed of rotation had to be raised in order to obtain a homogeneous grey. Even faster rotation was required when the eye was fixed upon a point b even farther to one side etc.

In Table VIII, I give the results of two series of experiments for the horizontal meridian of the right eye. It is obvious that /487
the speed of rotation had to be increased with increasing distance of the object from the center of the field of vision. A higher degree of accuracy cannot be attached to these experiments, since the evenness of the motion of the device left something to be desired, and since the blending of the black and white into grey did not go as easily as with rotating discs. Even with very fast rotation, horizontal strips were occasionally observed and these greatly interfered with the certainty of the estimate.

We now inquire as to the explanation for this phenomenon. We saw above that the rotation speed had to be raised when the illumination was intensified. The same thing occurs when the object is displaced toward the periphery of the field of vision, so that it seems reasonable to conclude that both phenomena have the same cause, i.e. that there is intensified excitation of light-sensitive organs on the periphery of the retina. In other words: the peripheral regions of the retina are more light-sensitive than the central ones.

TABLE VIII.

EXPERIMENT A

Angle to center of visual field	Outward		Inward	
	Required rpm	No. white lines per/sec	Required rpm	No. white lines per/sec
0°	0.815	111.66	0,645	88,37
5 3/4	0,96	131.52	0,806	110,42
9	1,15	157.55	0.978	133,98
12 1/2	1.3	178.1	1.111	152,21
16 3/4	1,467	200,98	1,311	179.61

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EXPERIMENT B

Angle to center of visual field	Outward		Inward	
	Required rpm	Black/ white changes/sec	Required rpm	Black/ white changes/sec
0°	0.654	89.60	0.605	82,89
5 3/4	0,85	116,65	0,8	109,6
9	1,02	139,74	0,976	133,71
12 1/2	1.075	147,28	1.087	148,92
16 3/4	1,408	192,90	1,316	180,29

Professor Wundt drew my attention to the fact that the distribution of retinal elements might also play a role, so that the previous explanation might not be the only possible one for this phenomenon.

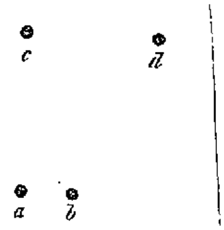

Fig. 5.

If a and b (Fig. 5) are two adjacent retinal elements of the fovea centralis, while c and d are two adjacent elements in the peripheral region, it is quite true that when a black/white disc is rotated in front of the eye, the black and white sectors will alternate just as often in a given time at c and d as at a and b. As is well known, however, we interpolate sensations in interval between the two nerve elements. If the points c and d are twice as far apart as a and b, a black sector takes twice as long to get from c to d; consequently, the region between c and d will retain the "black" sensation twice as long as between a and b. Regarding interpolation, there are now three al- /488
ternatives. First, all the elements surrounding such a region can be excited by white light, and in this case the interval is filled in with the "white" sensation; second, they are all excited by black, so that the interpolated sensation is "black". Finally, some of the retinal elements can be excited by black, and some by white. In this case, the region is filled out with the mixed sensation "grey". Obviously, at a given moment, in both the center and the periphery, some of the spaces will be filled out with black, others by white, and the third group by grey, so that the retinal point involved could be compared with checkerboard with three different kinds of squares. However, since these squares of the checkerboard are larger and change more slowly in the peripheral regions than in the center, it will be harder to make them blend together, so that a higher speed of rotation is required for these regions.

Earlier (Fig. 3), it was shown that the drop in brightness of the retinal image caused by the diaphragm arrangement of the eye could be represented by a curve similar to the cosine, while the line corresponding to the actual brightness sensitivity situation would have to deviate somewhat from the straight line. We are now in a position to determine this line more precisely, at least part of it, on the basis of the experiments shown in the tables. In Fig. 6, PQ /489 is the curve of objective brightness of the retinal image. To construct PR, we use the values given in Table V, "left eye, outward", as the ordinate. Thus, PR represents the actual brightness sensitivity. If we now attempt to derive the curve substituted for the actual sensitivity curve (which cannot be determined) by adding the ordinates of PR and PQ, we obtain the curve PS, which is very close to a straight line. Even if one of the other tables were used for this representation, the substituted curve would be almost a straight line. For instance, see Fig. 7, which is based on the sensitivity values given in Table IV.

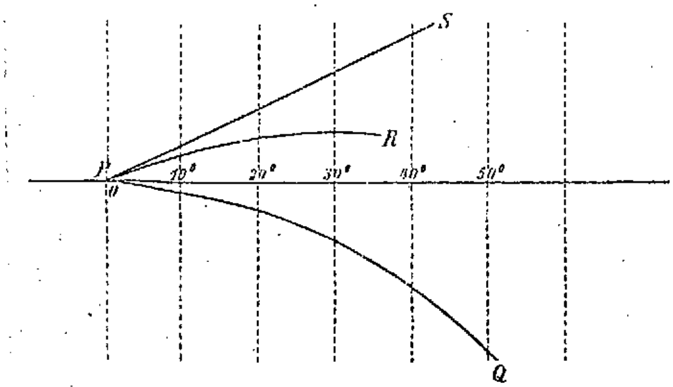

Fig. 6.

We have now grasped that the decrease in objective brightness of images toward the periphery of the retina caused by the physical nature of the dioptric apparatus of our eye is not only nullified but actually overcompensated for by the increased sensitivity of the retinal periphery. In fact, the maximum brightness sensitivity on the horizontal meridian is about 22 1/2-25° from center on the temple side, and about 5° further out on the nasal side. On the horizontal meridian, the maxima /490

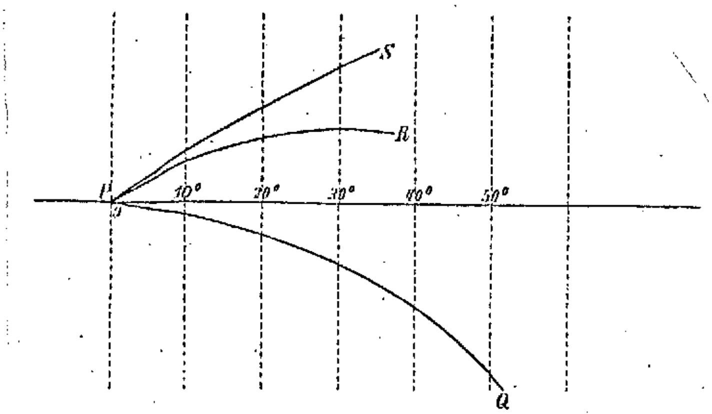

Fig. 7

are about 12.5-15° from the center, and the sensitivity is considerably lower, particularly on the lower half of the retina. Since I was able to make a precise study only of my own eye, the possibility cannot be ruled out that the eyes of other persons will have maxima at different positions, either because of original differences or because of differing adaptations. Indeed, as can be seen from the projection in Fig. 5, my two eyes do not behave identically. On the whole, most eyes should have similar properties.

This characteristic of our organ of sight, i.e. that the position of most acute vision is not the one most sensitive to light, is by no means a detrimental arrangement. On the contrary, it can be considered quite advantageous and useful. It offers substantial advantages for the eye's mechanism of motion; the enhanced sensitivity of peripheral areas results in increased innervation of the muscles of motion; therefore, relatively low intensities are sufficient to stimulate the eye to move toward the direction involved. The greatest relative motion stimulus will come from the points which have the greatest sensitivity. When we are out in the open or in front of a uniformly bright wall, and glance around freely, the eye actually moves within an angle of 20-25° in the horizontal direction and 10-15° in the vertical direction, or, combinations of the two. These motions are the most appropriate ones under the prevailing conditions. However, if we compel the eye to execute smaller or larger motions for some time, this requires a considerable effort and causes fatigue much more rapidly than usual; this occurs during proofreading and in reading very small print. The fact that objects must move with higher speed to blend in with their surroundings in indirect vision is of unmistakable value; it is precisely this property of our eye /491
which makes it possible to detect the motion of very small objects at the outer limits of our field of vision. Therefore, only a very small change in brightness or an extremely small change in position is required for indirectly viewed objects to attract our attention and to cause the eye to move toward them.

It is not the objective of this work to pursue the psychophysiological or physiological causes of this heightened sensitivity of the retinal periphery. Allow me to mention that someone else has conjectured that the outer members of the rods ought to be considered catoptric mechanisms. After discussing the function of crystal rods in the lower animals, which visibly had the character of refracting media, Wundt stated that the retinal layers in the eyes of vertebrates were arranged in opposite fashion; it was therefore likely that the crystal rods or outer members had become catoptric structures. "Once dioptric structures in the retina itself had become superfluous through the complete development of the refracting media in front of the retina, these structures could acquire a new role, acting as mirrors, reflecting some of the light which had passed through these visual cells back into them, and thus intensifying the process of visual stimulation" [7].

These studies reported in this work provide considerable support for this view. It is well known that the outer segments of the rods are not developed to the same extent, so that their action as catoptric instruments must be greater than that of outer segments of the cones. However, the point of most acute vision has only cones and no rods. Accordingly, the former are better suited for obtaining a sharp image of distinct objects. The cones thin out toward the /492
periphery, and the more light-sensitive rods begin to appear. Since both types, rods and cones, become less and less frequent toward the periphery, there must be a zone between the center and the periphery where the rods are densest. It would then be a problem in retinal anatomy to determine whether and to what extent the points of maximum rod density correspond to those of greatest brightness sensitivity. It is very tempting to believe that it is precisely the rods which do the job of compensating for the decrease in brightness toward the periphery caused by the dioptric equipment of the eye and creating the increase in sensitivity which we have found to be so important and useful an arrangement for indirect vision and motion in the human eye.

Rods are less numerous or completely absent in the retinas of birds, and this is further evidence for the above view. In the eyes of most birds, the shape, position, and distribution of the surface picking up the images and of the pupil are quite different, so that there is very little or no drop in objective intensity of images toward the periphery, unlike the situation in the human eye. This makes it unnecessary to compensate for this decrease in brightness, and moreover, because of the lesser mobility of the avian eye, enhanced sensitivity of peripheral retina areas is less desirable than in the human eye, it the catoptric instruments which we suspect the rods to be are not required.

SUMMARY

1. Sensitivity to brightness is greater in the peripheral regions of the retina than in the center.

2. This sensitivity is a maximum at a certain distance from the center, which depends on the direction, and then slowly declines further out.

3. The peripheral retina is more sensitive than the center /493
to rapid motion. In order to make the alternating sectors of a rotating disc blend into one another, a higher rate of rotation is required in indirect vision than in direct vision.

4. These properties of the eye seem very useful for vision, and offer substantial advantages with respect to perception of objects upon which the eye is not fixed and of motions occurring at the boundaries of the field of vision.

5. It is very likely that the outer segments of the rods, acting as catoptric instruments, bring about this increased sensitivity of the retinal periphery, which would also explain the different distributions of rods and cones in the human retina.

ADDENDUM

This article had been completed when a long treatise by A. E. Fick on perception of light and color appeared in Pflüger's Archiv für Physiologie [8]. Since this work also deals to considerable extent with the sensitivity of the retinal periphery, it would be a good idea for me to discuss Fick's results at this point.

It should first be mentioned that Fick's experiments aimed at determining the sensitivity of the retinal periphery differ fundamentally from mine in both method and scope. He attempted to determine the sensitivity of different points on the retina to intensities very close to the absolute or qualitative stimulus threshold, specifically with an eye adapted as well as possible. My experiments, on the other hand, were intended to discover the sensitivity of various parts of the retina under quite ordinary seeing conditions, i.e. average illumination of both the objects and the surroundings. Since /494
our investigations were conducted under quite different circumstances our results are incommensurable to a certain extent. The state of complete, or virtually complete adaptation to darkness is not a natural one for our organ of vision, but instead an artificially induced state and quite exceptional. Like any other organ, the eye will react to stimuli in a very different manner under abnormal conditions, so that inferences cannot be drawn with regard to the properties of the retinal periphery under ordinary illumination conditions, based on experiments with adapted retinas.

Fick's results are further impaired by the fact mentioned at the outset of his article, namely that a completely stationary retina can hardly be achieved and that maintaining the equilibrium state for the duration of the experiment must appear impossible. Since it is very dubious whether all retinal regions take the same time to reach complete adaptation -- the adaptation curves constructed by Aubert and Charpentier are in fact valid only for the center of the retina -- it must be admitted that all experiments aimed at determining the sensitivity of various parts of the retina in complete equilibrium cannot deliver altogether satisfactory results.

It appears that Fick entirely ignored two factors:

First, he makes no allowance for the fact, already cited by Aubert in his physiology of the retina, and discussed in my work, that retinal images on the periphery are objectively fainter than in the center of the retina, because of the arrangement of the refracting and screening systems in the eye. Fick's sensitivity values were already very high any way, and this factor increased them considerably.

Then in dealing with the question of whether separated or adjacent points of the retina assist in the recognition of a certain light intensity or quality, Fick fails to realize that the higher sensitivity of the peripheral retina must play a major role. If it were found that the sensitivity of the adapted retina 10-15° from the fovea centralis was 2-3 times or even 10-20 times that of the center of the retina, this would not mean that this substantial increase in sensitivity took place all at once at a particular point, and one must instead assume that the change was a continuous one, beginning at the center. It would then have to be conceded, however, that retinal images 32', 88' etc. in diameter, such as those used by Fick would have to impinge on points of higher sensitivity than the center. If it is now found that the intensity or color of a number of separate objects is recognized more easily and accurately at a large viewing angle, but under otherwise identical conditions, this does not mean that this is the consequence of mutual assistance between various points on the retina. Instead, it can be explained just as well by the higher sensitivity of the parts of the retina activated by a large angle of incidence. In any case, Fick's experiments do not refute Charpentier's hypotheses, since no allowance was made for the increase in sensitivity toward the retinal periphery.

In veiw of these circumstances, it is also easy to explain why the capacity for mutual assistance of separated parts of the retina will be found to be greater for colorless light than for colored light.

As for Fick's measurements of the sensitivity of peripheral parts of the retina, they cannot, as previously remarked, be compared with mine. The sensitivity of the peripheral retina found by Fick for the adapted eye is so high that it is completely out of /496 the question for the normal eye under ordinary illumination conditions. If, under ordinary viewing conditions, the sensitivity of the peripheral retina really was 2-3 or even 10-20 times that of the center of the retina, this enormous inequity would be very disturbing and unpleasant even in ordinary use of the eye. A uniformly illuminated surface of moderate extent and brightness would have to appear blindingly bright at its edges. However, nothing of the kind can be observed. On the contrary, apart from compensation for the objective brightness decrease of retinal images required by the optical construction of the eye, the sensitivity of the retinal periphery demonstrated in this work surpasses that of the fovea centralis by only a fraction, an amount which is still large enough to provide various substantial benefits for indirect vision, namely the recognition of faint objects and slight motions, while not large enough to cause major disturbances to our eyes in the fulfillment of their tasks.

The results of Fick's studies on the sensitivity of the retinal periphery to light may perhaps be valid in the case of complete or approximate equilibrium of the retina and for the use of very low intensities near the stimulus threshold; nevertherless, they obviously possess no validity for the ordinary use of our organ of vision.

The author attempts to reconcile the observation made at the conclusion of Fick's work, namely that a frosted glass plate illuminated by blue light can sometimes appear reddish purple, with the results of his studies on the sensitivity of the noncentral retina to colorless and colored light. The peculiar properties of blue glasses have also been found to be very disturbing at this Institute for Experimental Psychology in various research projects.

In fact, the same observation applies to any piece of cobalt glass held in front of a flame, and to any horse-carriage lantern. The light source always appears to be surrounded by a deep reddish /497 purple border. This is not due to the differences in sensitivity of the various retinal regions to the colors red and blue, but rather to the differences in deflection experienced by the two colors in the refracting media of the eye. Red and blue (more precisely, violet) are the colors most widely separated from one another in refractibility. If beams of just the two outer limits of refractibility are shown through or reflected from a surface -- as is the case, for instance, when reddish light from a petroleum or gas flame shines through blue cobalt glass -- the red and blue beams are refracted differently in the lens system of the eye, and since there are no other colors to average things out, the image of the red light no longer coincides with that of the blue. If one accommodates for the red image, the blue image can sometimes completely disappear if the object subtends a very small angle. On the other hand, if one accommodates for the blue image, the scattering circles of the red image generate a purple border, which is often very little or not at all inferior to the blue of the glass in saturation and intensity. In indirect vision, this phenomenon is less evident, namely because the sensitivity to red in indirect vision is lower and accommodation is less accurate than in the center of the retina and its immediate vicinity.

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